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Fin for heat exchanger and heat exchanger equipped with
such fins

5 The present invention relates to a corrugated fin for a
plate-and-fin heat exchanger and to an
evaporator/condenser comprising fins.

Various types of plate-and-fin heat exchanger are
10 available, each adapted to a field of application. The
invention applies advantageously to an
evaporator/condenser of a unit for separating air or
mixtures mainly containing hydrogen and carbon
monoxide, by cryogenic distillation.

15 The invention applies in particular to the main
evaporator/condensers of air distillation units. These
evaporator/condensers vaporize low pressure liquid
oxygen (typically slightly above atmospheric pressure)
20 collected at the bottom of a column, by condensation of
medium pressure nitrogen (typically 5 to 6 bar
absolute) flowing in passages neighboring the passages
dedicated to the flow of oxygen. The medium pressure
nitrogen is usually tapped off in the gas state at the
25 top of a medium pressure air distillation column to
which the abovementioned low pressure column is
connected. After its passage and at least partial
condensation in the evaporator/condenser, this nitrogen
is sent to the medium pressure column. It is more
30 specifically in the context of this application that
the invention will be described below, with the
understanding that its application can be considered in
other contexts.

35 The term "evaporator/condenser" also applies to
evaporators in which the heating fluid is a liquid that
is subcooled in the evaporator, instead of a gas which
condenses therein.

It also applies to intermediate evaporators/condensers at the top of a low pressure column, to evaporators/condensers at the top of an argon column, to evaporators/condensers at the top and in the vessel
5 of an Etienne column and to evaporators/condensers at the top of a simple column.

Cryogenic air separation installations of the double column type comprise an air compressor of which the
10 power consumption is determined in particular by the temperature difference between the oxygen vaporized in the low pressure column and the nitrogen present in condensed form in the medium pressure column. This temperature difference is itself linked to the pressure
15 difference between the two columns. A reduction of this temperature difference serves to considerably improve the power consumption of the air compressor, which is then required to supply air under a lower pressure than in the case of a higher temperature
20 difference.

To obtain this result, the best possible heat exchanges must be obtained in the evaporator/condenser, in other words, to obtain high heat transfer coefficients in its
25 various parts.

This optimization of the heat transfer coefficients has led to the design of relatively complex evaporators/condensers, because the fluids passing
30 through them are not found in the same physical state at all the levels of the apparatus. In particular, the oxygen is found in the completely liquid state in the bottom of the evaporator/condenser, and its proportion of vapor progressively increases as it rises in the
35 apparatus by thermosyphon effect because of its heating by the nitrogen gas.

The technology commonly used for these phase change heat exchangers is that of aluminum heat exchangers

with brazed plates and fins, which serve to obtain very compact members offering a large heat exchange area. These heat exchangers consist of plates between which corrugations or fins are inserted, thereby forming a stack of vaporization "passages" and condensation "passages". Various types of fins are available, such as straight fins (Figure 1), herringbone fins (Figure 2) and perforated or serrated fins (Figure 3).

The vaporization side of a bath "evaporator/condenser" has two separate heat exchange zones:

- a convective heat exchange zone in the lower part of the evaporator. The fins are in contact with a liquid phase and heat it to its saturation temperature.

- a boiling zone where vapor bubbles are produced from nucleation sites. The fins are in contact with a two-phase (liquid/gas) mixture. The higher the height at which the heat exchange occurs, the higher the proportion of gas.

The vapor bubbles appear on the wall as soon as local superheating reaches a certain value, which is called $\Delta T_{\text{boiling onset}}$ (local superheating being the temperature difference ΔT_{sat} between the wall temperature T_p and the fluid saturation temperature T_{sat}). This value varies according to the fluid and the structure and type of material employed.

Conventional theories of boiling show that, for a temperature difference ΔT_{sat} between the wall and the saturated fluid, a range of cavities present are able to provide nucleation sites. This range is limited by two extreme radius values r_{min} and r_{max} . For the cavity of radius r_{cav} lying between the two extreme values to be active, a liquid-vapor interface must subsist constantly in the cavity. Certain cavity shapes allow for greater stability of the liquid-vapor interface. If the interface is destroyed, a wider temperature difference is necessary to reinitiate the site. Hence

the shape of the cavities is an essential factor in the stability of the nucleation site and the performance of the heat exchange surface. A recessed cavity allows for high interface stability.

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A heat exchange area that promotes boiling must have the following characteristics:

- high density of cavities.
- cavity size and shape adapted to the fluid.
- 10 ◦ interconnected cavities for easier reinitiation.

These characteristics are reflected by a lowering of the value of the temperature difference of the first bubbles ($\Delta T_{\text{boiling onset}}$) and an increase in the heat
15 exchange coefficient.

The prior art describes several methods for producing a surface that intensifies boiling. These production methods can be grouped into the following three main
20 groups:

Mechanical treatment methods:

- *US-A-6 119 770*: production of tubes with porous surfaces on the interior or exterior of the tube.
25 Grooves are filled with metal particles and deformed.
- *US-A-4 216 826*: perpendicular grooves are excavated and deformed by means of rollers.
- *US-A-4 060 125*
- *GB-B-1 468 710*
- 30 - *US-A-3 906 604, US-A-3 454 081 and US-A-3 457 990.*

Etching methods:

- *US-A-4 846 267*: after a heating and cooling step, the surface is subjected to chemical etching by acidic
35 solution.
- *WO 0 223 115 (LACKS A NUMERAL!!)*: improvement of surfaces of integrated circuits. Cavities are created by laser etching.

Surface deposition methods:

5 - *EP-A-0 303 493*: spraying of a mixture of metal and plastic particles on a conducting surface. After vaporization at 500/600°C of the plastic particles, the surface displays a porous layer.

10 - *US-A-4 371 034*: plate evaporator configuration using porous surfaces on the vaporization side. The porous layer is formed by the high speed bombardment of molten particles on the flat surface or by bonding particles to the wall.

15 - *FR-A-2 443 515*: production of a porous surface of copper. The method consists in coating a tube or plate with a crosslinked organic foam and in depositing an electrolytic copper coating inside the foam. The foam is then pyrolyzed.

20 - *US-A-4 064 914*: production of a porous layer of copper or steel on a copper or copper alloy base. This porous layer consists of metal powder assembled by bonding and then brazed.

25 - *US-A-3 384 154*: use of a porous layer for boiling a liquid. This porous layer must be linked to a conducting metal wall and consist of conducting particles connected together and forming interconnected cavities. The manufacturing procedures are preferably sintering, welding, brazing and other methods. The thickness of the porous layer must be higher than the particle diameter and preferably smaller than three times the particle diameter.

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The problem is to obtain a heat exchange area that simultaneously satisfies the following requirements:

35 • an overall geometry of the fin type which can be brazed in a heat exchanger, particularly an evaporator/condenser,

 • a structure intensifying the boiling and of which the characteristics are a high cavity density, a cavity size and shape adapted to the fluid, and interconnected cavities.

Production methods by mechanical processing require a certain thickness of the conducting surface. These mechanical treatments are difficult to apply to the
5 fins used in an evaporator/condenser because the plate thicknesses vary between 0.2 and 0.5 mm.

Chemical and laser etching methods generate a limited surface finish because they have cavities at a single
10 level of the surface and which are not interconnected.

Only surface deposits provide a maximum cavity complexity to promote nucleated boiling. However, the techniques proposed in the prior art are methods which
15 cannot be applied simply to heat exchange surfaces of the fin type.

Sintered porous structures in corrugated form serve to obtain a fin type heat exchange surface having a porous
20 layer formed of a plurality of interconnected cavity diameters:

Sintered porous structures are commonly used in industry for gas and liquid filtration. The standard
25 products are made from stainless steel and bronze. However, the fabrication of a highly conducting material (such as copper or aluminum) is technically feasible. These porous materials can be produced with metal particles or metal fibers or even with metal
30 fabrics.

According to the invention, these porous structures of highly conducting materials are used for a heat transfer application and, more precisely, for the
35 nucleated boiling of a liquid.

We describe below their use in the form of a fin for insertion into a brazed plate-and-fin evaporator/condenser.

One of the parameters that varies the porosity of a sintered material is the size of the metal particles employed. In fact, the cavity diameters created after
5 sintering are directly conditioned by the size of the metal particles used.

It is possible to select a metal particle size to obtain cavities of a desired average diameter.

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These involve (mostly) aluminum particles of between 45 and 200 μm in size (3% > 200 μm and 15% < 45 μm).

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The porosity (after sintering) is 20%.

It is also possible to use several metal particle sizes to obtain a range of cavity diameters since boiling is promoted by a plurality of cavity diameters.

20 The distribution of the cavity diameters (particle size) is heterogeneous (random) if the metal particles are previously commingled.

25 The corrugation can be performed directly during the sintering by using corrugated molds, or by machining (electrical discharge machining) of grooves after sintering a thick porous plate.

30 A typical heat exchanger consists of a stack of identical parallel rectangular plates, which together define a plurality of passages for fluids for an indirect heat exchange relation. These passages are successively and cyclically passages for a first fluid, for a second fluid and for a third fluid.

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Each passage is bordered by closure bars which bound it while leaving inlet-outlet type windows for the corresponding fluid free. Corrugated spacers or fins are arranged in each passage to serve both as thermal

fins and spacers between the plates, particularly during brazing, and to prevent any distortion of the plates during the use of pressurized fluids, as well as a guide for the fluid flows.

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The stack of plates, closure bars and corrugated spacers is generally made from aluminum or aluminum alloy and is assembled in a single operation by furnace brazing.

10

Fluid inlet/outlet boxes, of general semicylindrical shape, are then welded to the heat exchanger body thus made in order to cover the ranges of corresponding inlet/outlet windows, and they are connected to fluid inlet and discharge lines.

15

In this industrial field, corrugated spacer of the serrated, straight or perforated straight type, are conventionally used.

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These corrugations are generally produced from aluminum strip and manufactured either using knurled wheels, with triangular or sinusoidal section channels and limited densities, or in a press.

25

It is therefore an object of the invention to propose a fin that overcomes the drawbacks of the prior art, and which can be used in industrial heat exchangers, particularly plate-and-fin heat exchangers of a unit for separating air or H_2/CO mixtures by cryogenic distillation, and in particular in an evaporator/condenser.

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For this purpose, the invention relates to a corrugated fin for plate-and-fin heat exchanger, of the type having a general main corrugated direction, and comprising a plurality of corrugations alternately linked by a corrugation peak and by a corrugation valley, characterized in that the corrugation sides,

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corrugation peaks and corrugation valleys are formed from a strip of sintered metal particles.

According to other features of the invention,
5 considered alone or in all technically conceivable combinations:

- the corrugation sides, the corrugation peaks and the corrugation valleys form straight segments, in cross section with respect to the main corrugation
10 direction, the peaks and valleys being parallel to each other;

- the particles are of aluminum, of an aluminum alloy containing at least 90 mol%. of aluminum, of copper, or of an alloy containing at least 90 mol%. of
15 copper;

- the fin has a thickness of between 0.25 and 0.6 mm; and

- the pores formed in the fin have a diameter of between 10 and 100 μm .

20 According to a further object of the inventor, an evaporator/condenser is provided, of the type comprising a stack of parallel plates, closure bars and, optionally, corrugated spacers, which define a
25 first series of passages for a fluid to be evaporated supplied at the source, and a second series of passages contiguous with the first for at least one fluid for heating said fluid to be evaporated, said passages of the first series being divided into three successive
30 zones, from the bottom to the top, of the evaporator/condenser:

- a first zone configured to promote heat exchange by convection;

- a second zone configured to promote nucleated
35 boiling;

- a third zone configured to promote convective boiling;

characterized in that at least the second zone and, optionally, the third zone, contains fins conforming to any one of claims 1 to 5.

- 5 Preferably, this evaporator is of the bath evaporator type.

According to a further object of the invention, an evaporator/condenser of the film evaporator type is provided, containing fins conforming to any one of claims 1 to 5.

According to a further object of the invention, an apparatus is provided for separating air by cryogenic distillation, comprising at least one evaporator/condenser as claimed in one of claims 6 to 8.

The apparatus may comprise at least two columns thermally linked together via an evaporator as claimed in one of claims 6 to 8.

These fins may be of the serrated, straight or perforated straight type.

25 The invention further relates to a heat exchanger equipped with at least one fin as described above.

The invention will be better understood on reading the following description, provided with reference to the figures appended hereto, of which Figures 1 to 3 show fins according to the invention and Figure 4 schematically shows a passage of an evaporator/condenser according to the invention, in which oxygen flows in the liquid and gas state.

A fin according to the invention has corrugation peaks 121, defined by the flat horizontal tops of the corrugation. It has corrugation valleys 122, defined

by the bottoms of the corrugation, which are also flat and horizontal. The peaks and troughs alternately link plane vertical corrugation sides 123, of which the median plane extends perpendicular to the direction D1.

5 The fins in Figures 1 to 3 have a thickness t of between 0.25 and 0.6 mm, and the pores (not shown) formed in the fin have a diameter of between 10 and 100 μm .

10 For further details concerning the overall design of the evaporator/condenser according to the invention applied to the distillation of air, reference can be made in a nonlimiting manner to application EP-A-1088578.

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The evaporator/condenser in Figure 4 is almost fully immersed in the liquid oxygen collected in the sump of the low pressure column of an air distillation unit. A passage is thus supplied "as source" with liquid oxygen. This liquid oxygen first enters a first zone of the passage 2 to be heated therein by the nitrogen flowing in contiguous passages of the evaporator/condenser. In this first zone, convective heat exchange is promoted, and the materials making it up are provided with a configuration maximizing this type of heat exchange. Typically, this first zone is packed with heat exchange fins with a high heat exchange area but nevertheless without causing excessive pressure drops, such as serrated fins (Figure 25 3) fins, or straight fins, whether perforated or not (Figure 1), or "herringbone" fins (Figure 2) defining numerous narrow corridors for the passage of the liquid oxygen. A density of at least 10 fpi (10 fins per inch of width or 3.9 fins per cm) is recommended, preferably 30 between 14 and 30 fpi (5.5 to 11.8 fins/cm). For example, use can be made of serrated fins of 26 fpi (10.2 fins/cm) offset at 1/8 inch (3.18 mm) intervals. In this first zone, the primary object is to obtain a rapid heating of the liquid oxygen, in order to heat it

to its saturation temperature. This first zone can extend to about $1/3$ of the total height of the evaporator/condenser, for example over a height of 40 cm for a 1.20 m high evaporator/condenser, a conventional size for an air separation unit. As a variant, the heat exchange corrugations could be replaced by a packing of a metal foam or of a material such as aluminum.

- 10 The oxygen rising in the passage then enters a second zone 3 where nucleated boiling is promoted by the formation of oxygen gas bubbles on the walls of the fins located in the passage. For this purpose, fins of sintered aluminum particles are used, so that the pores
15 of the fin increase the number of potential initiation sites. Pores or microreliefs may also be arranged on the walls of the heat exchanger plates bounding the passage. In fact, even more than in the first zone, it is important to limit the fluid pressure drops in order
20 to avoid hindering the upflow of the liquid oxygen/gaseous oxygen mixture present.

- The oxygen in liquid and gaseous form rising in the passage finally enters a third zone 4 where heat
25 exchange with the fluid passing through the contiguous passages is again promoted. The goal is to obtain convective boiling conditions therein. Fins made of sintered aluminum particles may also be installed there to promote the growth of the oxygen gas bubbles
30 present. The walls of the fins and plates are covered with a layer of liquid oxygen through which the heat exchanges take place. Its thickness mainly depends on the flow conditions of the liquid oxygen - oxygen gas mixture. Heat exchanges are promoted by higher fluid
35 velocities. It is therefore important to minimize the pressure drops of the oxygen as it rises through this third zone. For this purpose, to obtain a satisfactory compromise between low pressure drops and good heat transfers, it may be advisable to pack this third zone

with straight, optionally perforated, fins, with a density above 10 fpi (3.9 fins/cm), but lower than or equal to the fin density used in the first and, optionally, the second passage zone. Straight fins
5 perforated to 5% with a density of 10 to 40 fpi (3.9 to 5.5 fins/cm) would be consistent with the above examples. Serrated fins are not recommended here due to the fairly high pressure drops that they would generate.

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This third zone may represent about half of the total height of the passage, or 60 cm for a 1.20 m high evaporator/condenser.

15 At the outlet of the third zone 4, the gaseous oxygen GO emerges from the evaporator/condenser and rises to the top of the low pressure column, while the liquid oxygen LO descends in the sump of the same column.

20 It goes without saying that the examples given above are nonlimiting, and that other configurations are conceivable. In particular, each of the zones described above can be divided into several subzones having heat exchange surfaces that are configured in
25 different ways, provided that in each of these subzones, the process to which the corresponding zone is dedicated is effectively promoted: convective heat exchange for the first zone, nucleated boiling for the second zone, convective boiling for the third zone.

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The invention can also be applied in evaporators/condensers treating other gases than oxygen if the advantages that it has can be exploited therein.